

Coupled Growth of Two Phases in Eutectic and Peritectic Systems

Personnel: Rohit Trivedi (PI), Iver Anderson (PI), J-H Lee (Post Doctoral Scientist), Shan Liu (Research Associate), Ralph Napolitano (PI)

Abstract:

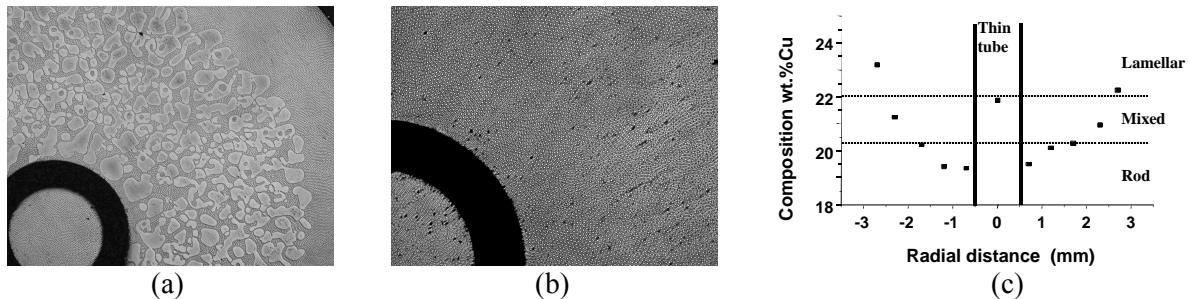
Although significant studies on eutectic systems have been carried out in the past, some critical fundamental questions still remain unanswered. The following several critical aspects of coupled growth are being examined in this study: (i) the range of stable spacing under fixed growth conditions; (ii) the influence of interface energy and its anisotropy on the lamellar to rod transition; (iii) the disorder in the spacing caused by the presence of fluid flow in the melt; (iv) the ability to form coupled (or cooperative) growth of the two phases in peritectic systems; (v) the stability of eutectic structure under rapid solidification conditions. To study these aspects we are carrying out extensive studies in Al-Cu, Al-Ni and Al-Si systems.

Recent Results:

Most experimental studies in metallic systems have been carried out under conditions where significant fluid flow is present in the Bridgman growth. Prior to using the experimental results to validate the models, or to refine the models, we first examined how the fluid flow influences the eutectic structure. The fluid flow effects were examined through solidification in a fine tube that was embedded in a larger diameter sample. The microstructure inside the fine tube would be controlled by diffusion, whereas the microstructure in the region outside the thin sample will be influenced by convection. Experimental results showed that the convection effects are negligible if the composition is precisely the eutectic composition. In this case, the solutal boundary layer is very thin, of the order of eutectic spacing, so that it is not influenced by fluid flow in the melt. However, significant changes in eutectic structures were observed when the eutectic structure was obtained in off-eutectic compositions.

When fluid flow is present, a gradient of microstructure is obtained from the center to the wall of the sample. This is due to radial composition variation caused by fluid flow in a system having a solute with density higher than that of the solvent (e.g. the Al-Cu system). The radial redistribution of solute gives rise to lower composition near the specimen center where rod eutectic forms. In contrast the higher composition near the wall forms a lamellar eutectic, we also observed that there is no sharp transition between the rod and lamellar eutectic regions, and a rod-lamellar region exists over a range of compositions. Detailed composition measurements have been carried out to correlate the composition with microstructure.

Detailed experimental and theoretical studies have been initiated to examine the rod-lamellar transition, and to examine the effect of interface energy on the transition.



(a) Transition from primary phase to eutectic with fluid flow. (b) A transition from rod to lamellar eutectic with fluid flow. (c) Radial concentration profile causing rod to lamellar transition.

One of the critical questions in eutectic growth is the selection of spacing since a range of spacing has been observed. The minimum stable spacing is assumed to correspond to the minimum undercooling, whereas the maximum stable spacing has not yet been established. At issue is the validity of minimum undercooling as the smallest stable spacing. This has been based on the assumption that the slope of the undercooling-spacing relation must be positive for the stability of eutectics. However, eutectic-type microstructures have been observed in peritectic systems where the undercooling-spacing variation has a negative slope. There are still questions as to whether the coupled growth in peritectics is steady-state growth or whether it occurs only in a transient regime. Experimental data are not conclusive since fluid flow is generally present in bulk samples that can influence the stability of the microstructures. We have carried out detailed experimental studies in the peritectic system of Al-Ni with negligible convection and observed both the banded and the coupled growth regimes.

Experimental studies on the stability of eutectic structures in hypereutectic Al-Cu alloys show the formation of highly regular and faceted microstructure of the primary θ -phase. These experimental observations are now being quantitatively examined through the reconstruction of the three-dimensional shape by using micromilling. This provides a physical picture of the dynamic evolution of the facet phase, facilitating the development of for the case where anisotropy of interfacial energy is large. No acceptable modeling for such faceted phases has been done so far for directional solidification conditions.

Under rapid solidification conditions, a very fine eutectic spacing is observed. However, above a certain critical velocity, the eutectic morphology becomes unstable and forms cells/dendrites or irregular eutectic. The dynamical evolution of microstructure was thus studied in atomized droplets of Al-Si eutectic alloys, where the effects of droplet size on the variation of microstructure due to the recalescence were quantitatively established. The effect of solidification conditions on the selection of different morphologies was shown to control the properties of the material. Quantitative comparison with rapid solidification models were carried out, and a microstructure map for the Al-Si system was developed showing the correlation between composition, processing variables and properties. In very fine droplets, the formation of microcellular structure was observed, and the interface growth conditions at which microcellular structure became stable were determined.

Significance:

The strong effect of fluid flow on eutectic microstructure was quantitatively established. Fluid flow causes a gradient in microstructures and this variation can be related to the composition variation. The transition from rod to lamellar transition was found not to be sharp, but occurred over a range of compositions. The formation of a steady-state coupled growth in peritectic system under diffusive growth conditions was established. This indicates that coupled growth can be stable even when the undercooling decreases with an increase in spacing, which is contrary to the presently accepted ideas. A detailed characterization of the variation of microstructure with time was established in a rapidly solidified droplet to quantitatively determine the effect of recalescence.

Future Work:

The existence of a coupled growth in peritectic systems will be quantitatively studied under diffusive growth conditions and a theoretical model will be developed to establish its stability. Unanswered critical questions involve the dendrite to cell transition at very high velocities and the formation of a faceted primary phase ahead of the eutectic interface will be examined both experimentally and theoretically.

Interactions:

A significant interaction is present with Prof. Wilfried Kurz (EPFL, Lausanne) on the work on the coupled eutectic and peritectic growth.